BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.
Upton, New York

ACCELERATOR DEPARTMENT
Informal Report

INTERSECTING STORAGE ACCELERATOR NOTES

Consideration of the RF System for
the 15 GeV Electron Ring Option for ISABELLE

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August 7, 1972

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1. INTRODUCTION

The parameters used are based on the very tentative ring design existing at the time of the Summer Study. The most important of these are:

Electron Radiation Loss at 15 GeV	25 MeV/turn
Bending Radius	180 m
Gamma Transition (γ_t)	18
Maximum Current (15 GeV)	100 mA
Length available for accelerating cavities	100 m
Circumference of ring	1800 m

The choice of frequency depends on both RF power considerations and values of synchrotron oscillation frequency. However, changes in the lattice parameter could influence the conclusions. In particular, the value of γ_t strongly influences the synchrotron frequency and the peak voltages necessary to contain quantum fluctuations. The natural beam size however is also related to γ_t via the local values of the momentum function X_p and this may change in subsequent luminosity considerations in the ISABELLE design.

The very high radiation loss per turn (about 0.2%) raises the question of the distribution and location of the RF cavities. It might prove necessary

to make the local value of X_p zero in the cavity straight sections to avoid the possibility of significant induced betatron oscillations.

2. ESTIMATES OF RF PARAMETERS

The electron ring is assumed to have a bending radius of 180 m and a circumference of 1800 m. At the peak electron energy of 15 GeV, the radiation energy loss per revolution is 25 MeV.

Additional bending will almost certainly be required at or near the interaction region, and this will lead to further radiation loss. The present estimates neglect this added requirement.

The peak voltage required in the RF system is given in Table I as a function of the RF harmonic number, h , for the following assumptions:

γ (transition) of the electron ring lattice	= 18.0
Damping Time Constant of Synchrotron Oscillations	= 3.6 msec
Beam Lifetime Time Constant due to Quantum Effects	= 10 hours

TABLE 1. Peak Voltage as a Function of Harmonic Number

h	Frequency (MHz)	Synchronous Phase, ϕ_s	Peak Voltage (MV)
6000	1000	30°	50
4800	800	33°	46
3600	600	36.5°	42
2400	400	41.5°	38
1200	200	50°	32.5°

The choice of the RF frequency is also influenced by the resulting values of the synchrotron oscillation frequency, f_s . The ratio of the frequency, f_s , to the electron revolution frequency, f_r , is given by the parameter, Q_s , where

$$Q_s^2 = hV \cos\phi_s / 2\pi E \gamma_t^2$$

with

- V = peak RF voltage,
- E = electron energy, and
- γ_t = γ (transition)

The variation of Q_s is given in Table II.

TABLE II. Q_s as a Function of h

h	Frequency (MHz)	f_s (kHz)	Q_s
6000	1000	15.0	0.09
4800	800	13.3	0.08
3600	600	10.3	0.062
2400	400	7.8	0.047
1200	200	4.8	0.029

From the point of view of the RF system and the synchrotron motion it is advantageous to have a high value of γ_t . The required overvoltage is

reduced, together with the value of Q_s . In a normal magnet lattice high γ_t is associated with low values of X_p , and correspondingly low values of the equilibrium betatron amplitudes of the electrons.

For the assumed value of $\gamma_t = 18.0$, the Q_s value is 0.09 at the peak RF frequency considered of 1000 MHz. It is further increased if there is additional bending introduced at the interaction regions. The Q_s value is reduced to an acceptable level at the RF frequencies ≤ 600 MHz approximately.

At the interaction region of the 15 GeV electrons and the 200 GeV protons, the proton radial beam size is approximately 25% larger than the natural electron radial beam size (for a minimum β value of 5 cm in the e ring). Thus, any significant stimulated electron betatron motion will lead to a reduced luminosity. Such motion may result because of the large energy gains in the accelerating sections. Assuming that two medium length straight sections are used for the RF, the approximate energy gain in each straight is 12.5 MeV, giving a $\Delta p/p = 0.8 \times 10^{-3}$. The direct induced betatron motion depends on the choice of the lattice parameters in the straight and on the phase shift of the betatron motion between individual accelerating structures. If all structures are oriented to give added motion, the effect is significant for typical lattice parameters of $\beta_x \approx 20$ m, and $X_p \approx 1.5$ m. The effect may be eliminated by making X_p zero. When the final lattice is determined, the effect can be computed to see if this is necessary.

3. ACCELERATOR CAVITY AND RF POWER CONSIDERATIONS

Since the straight sections space available for accelerator cavities is limited in a storage ring, it is desirable to use cavities with as high a

shunt-impedance as possible. Also to limit the number of power feeds, chains of coupled cavities should be used. Cavity chains with very high shunt-impedance have been designed and successfully operated in an electron linac at Los Alamos. In these cavities power transfer is accomplished by off-line cavities. Shunt-impedances of 40 $\text{M}\Omega/\text{m}$ at 800 MHz are obtainable. This type of cavity could be scaled to the desired frequency with the shunt-impedance per unit length $r_\ell(f)$ for copper being given by:

$$r_\ell(f) = (2f)^{\frac{1}{2}}$$

where r_ℓ is in $\text{M}\Omega/\text{m}$ and f in MHz.

A practical lower frequency for these cavities because of size consideration is about 200 MHz when the cavity diameter is about 1 meter. An upper frequency limit is probably below 1000 MHz since the requirement of a large center-hole between cavities results in a drop in the shunt impedance at frequencies where the hole becomes a large fraction of a wavelength. The large center hole is required for filling conditions.

Using a cavity design with the shunt-impedance given by Equation (1), the power needed to obtain a given peak voltage $V(f)$ is given by:

$$P_\ell = \frac{V^2(f)}{r_\ell} \quad (2)$$

or

$$P_\ell = \frac{V^2(f)}{(2f)^{\frac{1}{2}}} \quad (3)$$

The units of (3) are MW.m and dividing P_ℓ by the total length of the cavities gives the power-to-wall losses.

With the values given in Table I, P_e is plotted as a function of frequency in Fig. 1. For 100 m of cavities the power requirement is 510 kW at 400 MHz increasing to 560 kW at 1000 MHz. There is a very shallow minimum in the 400 to 600 MHz range. The beam current at 15 GeV is 100 mA giving a power demand to the beam of 2.5 MW. Thus the total power required at 15 GeV with 100 m of cavity is about 3.1 MW at 400 MHz. The region 400 to 500 MHz is a convenient frequency range both for cavity size (about 50 cm in diameter) and for availability of high power CW Klystrons. For a choice of frequency of 400 MHz and for 100 m of standing wave coupled cavities in the $\pi/2$ mode 267 cavities result. These could be dispersed around the ring in groups of 45 cavities, each group energized by a single 500 kW klystron. The cost of these klystrons should be about \$800,000, the cavity about \$500,000. With Instrumentation, controls and power supply about \$1,200,000, and with Engineering, Design and Inspection of \$700,000, the total price would be about \$3,300,000. This is a very crude cost estimate.

4. CONCLUSIONS

For the present lattice design the favored frequency is approximately 400 MHz, where the peak RF voltage is 38 MV. At the design current of 100 mA, the total RF power requirement is about 3 MW. The distribution of cavities is subject to further lattice study.

Fig. 1 Total Wall Losses as Function of rf Frequency.